

A Fuzzy Structural Matching Scheme for Space Robotics Vision

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Fuzzy logic, stereo matching, robot vision, space robotics

ABSTRACT

In this paper, we propose a new fuzzy structural matching scheme for space stereo vision which is based on the fuzzy properties of regions of images and effectively reduces the computational burden in the following low level matching process. Three dimensional distance images of a space truss structural model are estimated using this scheme from stereo images sensed by Charge Coupled Device (CCD)TV cameras.

INTRODUCTION

The importance of advanced space vision processing has increased in the space station era for servicing, maintenance, repairs and assembly by space teleoperated /robotics systems. A stereo vision system with passive optical image sensors (CCD TV cameras) is the simplest method of sensing and perceiving the three dimensional (3-D) distances and attitude parameters of targets objects using the stereo process of matching and the principle of triangulation. Because of the simplicity of the imaging equipment and recent advance in the processing speed of computers, this stereo vision system is ex-

pected to become a key technology for space automation and robotics [Ref. 1,2]. However, the techniques of stereo images processing are insufficient so far, only the disparity map of targets objects can be extracted from their stereo images of uncooperative (without special reflector or pattern marker) targets objects in the space environment.

In this paper, we propose a new fuzzy structural matching scheme and give an example of its application for a space truss structural model. This paper consists of two parts. In the first part, a scheme for higher level structural stereo matching algorithms is discussed in terms of the fuzzy based properties of labeled coarse regions of stereo images. In the second part, the evaluation experiments for the fuzzy stereo matching scheme and fuzzy-based feature extraction are carried out using CCD images of simple objects (a space structural model).

HIGHER LEVEL STRUCTURAL MATCHING ALGORITHMS

Matching of the left and right images, the so-called correspondence problem, is one of the most critical subjects in the field of computer vision processing. Finding conjugate points of images can be performed in several ways such as gray-level matching, local correlation methods, edge matching, and dynamic programming. However, these methods are less reliable and less efficient than

higher level structural methods as such segment- or region- based methods, because these methods depend basically on point matching.

A proposed matching algorithm is fundamentally based on the matching boundary-representation (B-rep) of stereo images as proposed by F. Tomita et al [Ref. 3]. To apply this method to the images of objects resulting in space optical environments, we modified this matching scheme using the fuzzy set theory for region matching as a higher level structural correspondence [Ref. 4]. An outline of the proposed matching scheme with fuzzy properties of regions is as follows. The properties of each region of segmented images consist of perimeter L , averaged gray level X , and aspect ratio T . The similarity measure of the perimeter for correspondence between the left region (i) and the right region (j) of images is defined as follows.

$$P_L(i,j) = \begin{cases} 1 & \Delta l_{ij} \leq m - \sigma \\ -\frac{1}{2\sigma} [\Delta l_{ij} - (m - \sigma)] + 1 & \Delta l_{ij} \geq m - \sigma \end{cases} \quad (1)$$

where $\Delta l_{ij} = \text{abs}(l_{Li} - l_{Rj})$

$$m_i = \frac{1}{MN} \times \sum_{i=1}^N \sum_{j=1}^M \Delta l_{ij}$$

$$\sigma_i = \frac{1}{MN} \times \left[\sum_{i=1}^N \sum_{j=1}^M (m_i - \Delta l_{ij})^2 \right]^{1/2}$$

l_{Li} ; perimeter of i -th region of left image

l_{Rj} ; perimeter of j -th region of right image

M, N ; number of regions

The characteristic curve of membership function of this equation is shown in Figure 1.

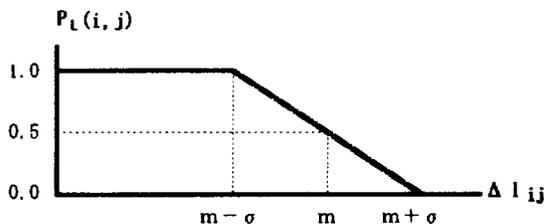


Figure 1. Membership function of $P_L(\text{perimeter})$

This similar equation is also used for other

property X . The similarity measure of the aspect ratio T is defined as follows.

$$P_T(i,j) = \begin{cases} \Delta t_{ij} & \Delta t_{ij} \leq 1 \\ \frac{1}{\Delta t_{ij}} & \Delta t_{ij} > 1 \end{cases} \quad (2)$$

where $\Delta t_{ij} = t_{Li} / t_{Rj}$

t_{Li} ; aspect ratio of i -th regions of left image

t_{Rj} ; aspect ratio of j -th regions of right image

The Total similarity measure of region properties for correspondence between the left and right regions of images, $R(i,j)$, is calculated as follows:

$$R(i,j) = \text{Min}(P_L(i,j), P_X(i,j), P_T(i,j)) \quad (3)$$

and $R(i,j) > \text{threshold } R_0$,

This higher level structural correspondence (region based) is performed at the first phase of matching computations. In this way, the search space of the second phase for low level structural matching (segment based) can be narrowed. Total processing flow of this hierarchical matching is shown in Figure 2.

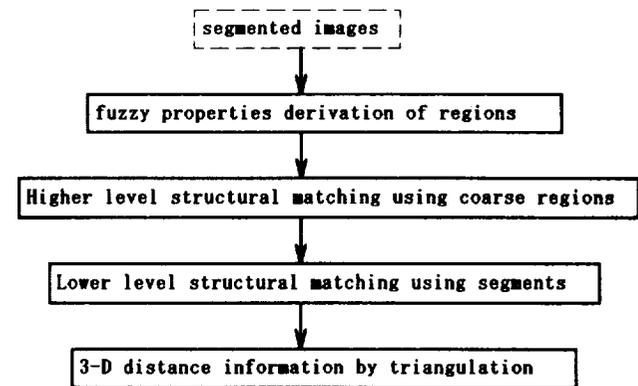


Figure 2. Hierarchical structural matching scheme using B-rep of stereo images

LABORATORY EVALUATION EXPERIMENTS

The evaluation experiments of the fuzzy-based edge feature extraction and stereo matching algorithms were performed using CCD images from models of target

objects. As a simple model of target objects, we use a building block model and a space truss structural model setup on an optical bench in the laboratory. The low contrast and/or blurred digital images of the target objects are generated by a CCD TV camera

onboard a x-y traverse device and a Sun workstation equipped with an image digitizer. A digital image is represented by an array of 512X480 (=MxN) pixels, and 8-bit gray levels. Image processing flow for evaluation experiments is shown in Figure 3.

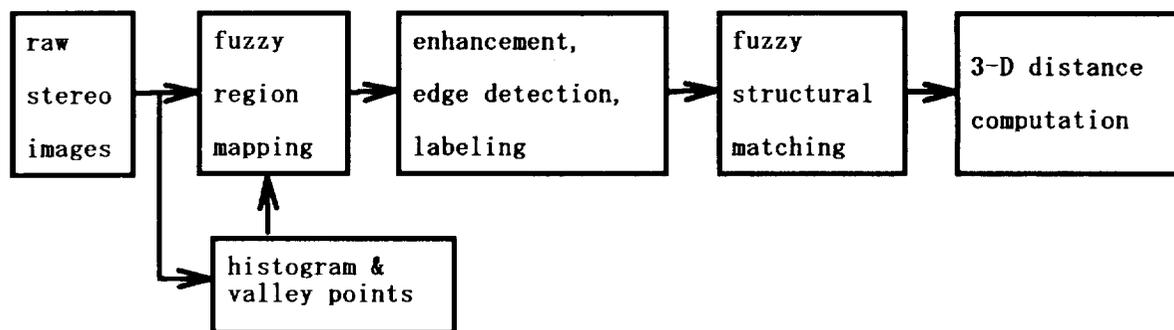


Figure 3. Image processing flow for estimation of 3-D distance informations

Figure 4(a) shows an original stereo image of a space truss structural model. The edge feature detected and labeled image from the original image are shown in Figure 4(b). A 3-D distance image of the object estimated by the proposed matching scheme and triangulation for labeled images is shown in Figure 4(c). In this experiment, the number of coarse regions correspondence was reduced to almost half by using a proposed structural matching scheme.

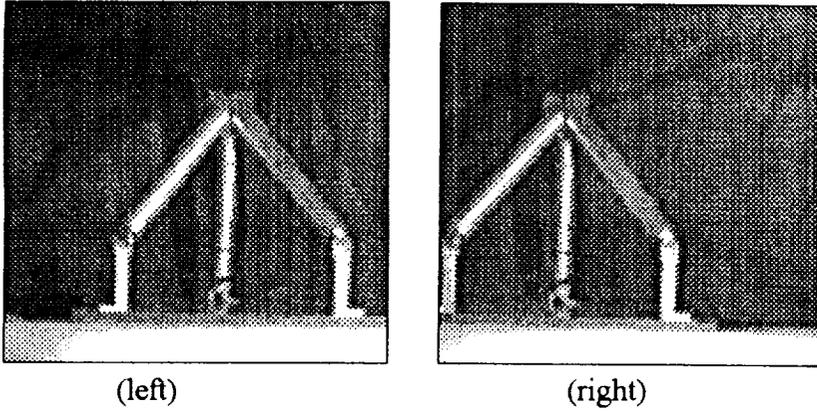
CONCLUSIONS

As a part of the research on stereo vision processing algorithms for aerospace applications, a stereo matching scheme based on the fuzzy set theory has been studied. It has been concluded that: (1) A higher level structural matching scheme for labeled images is very effective for reducing computational burden, (2) Three dimensional distances are relatively

well estimated in a block model and a space truss structural model.

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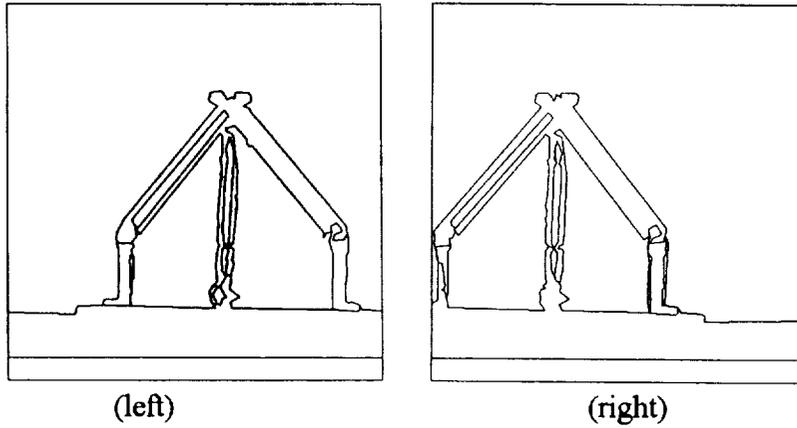
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(left)

(right)

Figure 4(a) Original stereo image of a space truss structural model



(left)

(right)

Figure 4(b) Segmentation images of a space truss structural model

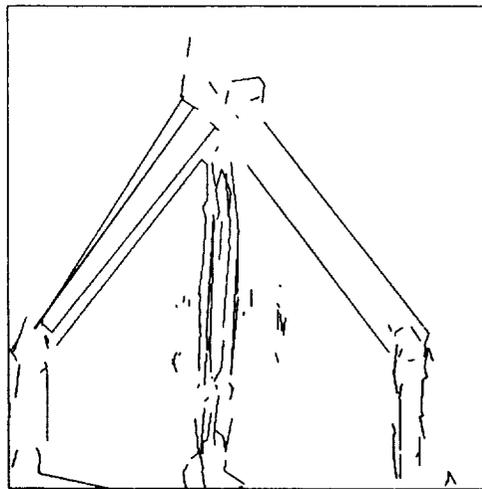


Figure 4(c) 3-D distance image of a space truss structural model